

ATMOSPHERIC INFLUENCE ON NDVI DETERMINATIONS FROM VARIABLE RED AND NEAR INFRARED AVIRIS BAND POSITIONING

Romero da Costa Moreira¹ and Lênio Soares Galvão²

¹Instituto de Estudos Avançados - IEAv

Caixa Postal 6044, 12231-970, São José dos Campos, SP, Brazil.

²Instituto Nacional de Pesquisas Espaciais - INPE

Caixa Postal 515, 12231-970, São José dos Campos, SP, Brazil.

1. INTRODUCTION

Spectral vegetation indices are combinations of spectral values obtained from two or more remote sensor bands, generally the Red (R) and the Near InfraRed (NIR) spectral regions. The determination of these indices is important not only for the monitoring of the vegetation at a global scale, but also to allow the prediction of some vegetation parameters. A vegetation index frequently used in global vegetation studies is the Normalized Difference Vegetation Index - NDVI (Rouse et al., 1973) that relates spectral data according to the equation $NDVI = (\rho_{NIR} - \rho_R) / (\rho_{NIR} + \rho_R)$, where ρ_{NIR} is the reflectance value in the NIR band and ρ_R is the reflectance value in the R band.

Several works have shown the correlation of these indices, in particular the NDVI, with vegetation parameters such as biomass (Holben et al., 1980), Leaf Area Index - LAI (Asrar et al., 1985), and Absorbed Photosynthetically Active Radiation by vegetation canopy - APAR (Epiphanio and Huete, 1994). For instance, Elmore et al. (2000) obtained a coefficient of determination (r^2) of 0.83 from field measures of Percent Live Vegetation Cover and NDVI values obtained from a temporal image series (from 1984 to 1997) of the Thematic Mapper (TM) sensor. However, besides the vegetation itself, several factors influence correlations between vegetation indices and vegetation parameters. These factors include the soil (Huete, 1989) and the atmosphere (Carlson and Ripley, 1997) influences, the topographic effects (Slater, 1980), the illumination and viewing geometry (Epiphanio and Huete, 1995), and sensor characteristics such as band positioning and bandwidth (Galvão et al., 1999).

In relation to the atmosphere influence, Teillet et al. (1997) concluded that atmospheric effects could cause variations in vegetation index values depending on band positioning and bandwidth. In fact, the atmosphere modifies the radiation reflected by the surface in two ways. First, it introduces an additive component that increases the spectral values obtained by remote sensors. This effect is known as scattering, which happens more strongly in shorter wavelengths (ultraviolet and visible), being reduced progressively towards longer wavelengths (near infrared). Second, some atmospheric components such as oxygen and water vapor absorb selectively the radiation. Because of the spectral dependence of these effects, the spectral characteristics of the sensors are important to enhance or minimize the atmospheric influence. Thus, NDVI values obtained for the same area from different sensors having distinct spectral band positioning and bandwidth can show quite different values, depending on the target and on the relative positioning of the R-NIR bands face to the spectral location of the main atmospheric features.

The objective of this work is to discuss the basic problem of NDVI variations considering the atmospheric effects and the band positioning and bandwidth influences. For this purpose, the position and width of narrow and broad R and NIR bands, including those from some multispectral sensors, were simulated from AVIRIS (Airborne Visible/InfraRed Image Spectrometer) data collected in central Brazil, and NDVI values were calculated and compared from apparent and surface reflectance images.

2. METHODOLOGY

The AVIRIS radiance image was collected on August 20, 1995, in central Brazil. The study area is 90 km from Campo Grande city (State of Mato Grosso do Sul) and is centered in the coordinates 19°53'S/53°45'W. The data were acquired in 224 contiguous bands of less than 10 nm of width, in the 400-2500 nm spectral region, from 20 km of altitude and with a spatial resolution of 20 m.

The radiance data were converted into surface reflectance images (ρ_s) by using a MODTRAN-based method that minimized the effects of atmospheric absorption and scattering due to several constituents (e.g., water vapor, carbon dioxide, oxygen) (Green et al., 1991). For the conversion of radiance data into apparent reflectance images (ρ_a), that is, not corrected for the atmospheric influence, the following simple equation was used (Latorre et al., 1998):

$$\rho_\lambda = \pi L_\lambda / E_\lambda \cos \theta_s$$

where ρ_λ is the spectral reflectance, L_λ is the spectral radiance, E_λ is the spectral irradiance on the top of the atmosphere (complementary information accompanying the radiance-image) and θ_s is the solar zenith angle obtained to the central point of the scene, considering the date and time of image acquisition. In the present investigation, θ_s was of 31°.

By using these two datasets (ρ_s and ρ_a), narrow and broad R (10, 20, and 50 nm of width) and NIR (10, 100 and 200 nm of width) were simulated from endmember spectra of green vegetation (GV) and soil (S) selected from the ρ_s images through the sequential use of the Minimum Noise Fraction (MNF) and the Pixel Purity Index (PPI) techniques (Green et al., 1988; Boardman and Kruse, 1994; Boardman et al., 1995). Furthermore, the nominal intervals of the R and NIR bands of some multispectral sensors listed in Table 1 were also simulated.

NDVI values were then calculated from both datasets (ρ_s and ρ_a) and from the endmember spectra (GV and S), as a function of a variable band positioning and bandwidth, to assess the predominant influence of atmospheric scattering on the R interval and of atmospheric absorption on the NIR interval, and their effects on the vegetation index calculation.

3. RESULTS AND DISCUSSION

Figure 1 shows AVIRIS-derived apparent and surface reflectance spectra of green vegetation (riparian forest) and the positioning of R and NIR bands of some orbital multispectral sensors. The nominal intervals, center and width of the R-NIR bands usually used in the determination of the NDVI are listed in Table 1. As indicated in this figure and in this table, the sensors acquire data with bands placed at very different positioning and with variable width. Furthermore, the NIR bands of instruments such as AVHRR and MSS encompass spectral intervals of strong atmospheric absorption by water vapor (e.g., 940 nm absorption band). In the visible interval, the main effect of the atmosphere is related to scattering by gases and aerosols, whereas in the NIR interval oxygen and especially water vapor produce well-defined absorption bands, as visualized in the apparent reflectance spectrum.

Apparent and surface reflectance spectra of the selected endmembers are shown in Figure 2 in the full range of 450-2500 nm. The GV spectrum is from the riparian forest, the green vegetation that occurs along the drainage streams in the study area. Its surface reflectance spectrum presents the characteristic chlorophyll absorption bands in the blue and red intervals, the reflectance peak in the green, the absorption features due to leaf water in 960 and 1200 nm, and the lignin/cellulose features around 2100 and 2300 nm. The S spectrum is from *Latossolo Vermelho-Escuro* (oxisol). Its surface reflectance spectrum displays a broad absorption band at 900 nm,

due to hematite, and a well-defined narrow feature at 2200 nm due to kaolinite. These GV and S spectral characteristics are affected in the visible interval by atmospheric scattering and in the NIR interval by atmospheric absorption. The strongest water vapor absorption bands are located at 1400 and 1900 nm, spectral intervals not used in conventional remote sensing investigations.

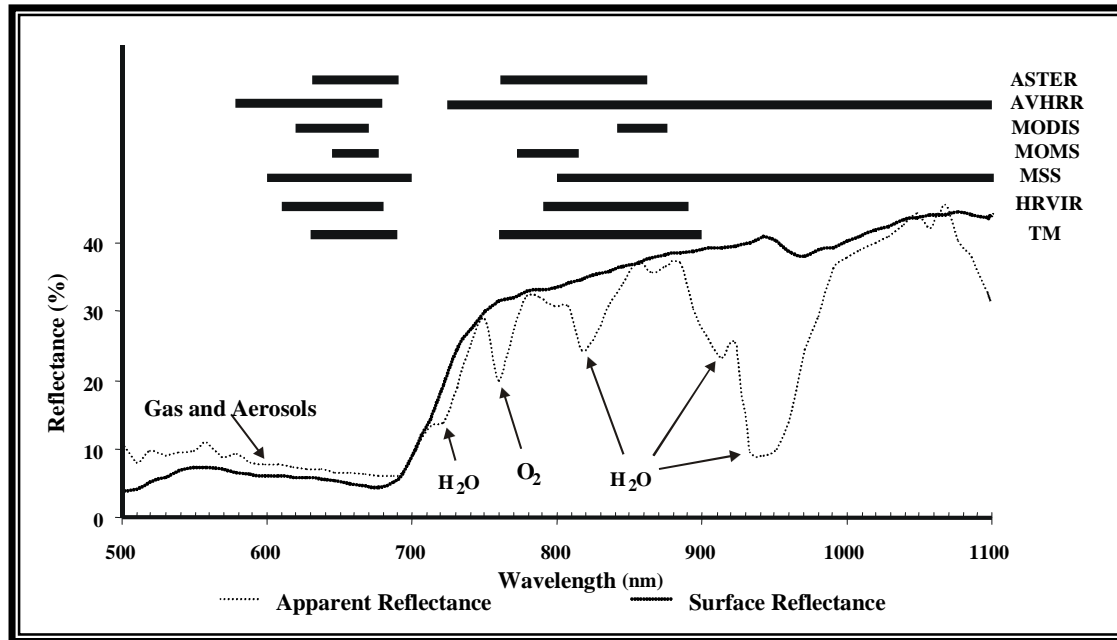


Figure 1 – AVIRIS-derived surface (continuous line) and apparent reflectance (dashed line) curves of green vegetation (riparian forest). The main atmosphere constituents responsible by well-defined absorption bands are indicated. The horizontal bars represent the nominal intervals of R and NIR bands of the sensors listed on the right side of the illustration.

Table 1. Spectral nominal intervals of the R and NIR bands of some orbital multispectral sensors

<i>Sensor</i>	<i>R Band (nm)</i>			<i>NIR Band (nm)</i>		
	<i>Interval</i>	<i>Width</i>	<i>Center</i>	<i>Interval</i>	<i>Width</i>	<i>Center</i>
ASTER/Terra	630-690	60	660	760-860	100	810
AVHRR/NOAA 14	580-680	100	630	725-1100	375	912
MODIS/Terra	620-670	50	645	841-876	35	858
MOMS-2	645-677	32	661	772-815	43	793
MSS/Landsat 5	600-700	100	650	800-1100	300	950
HRVIR/SPOT 4	610-680	70	645	790-890	100	840
TM/Landsat 5	630-690	60	660	760-900	140	830

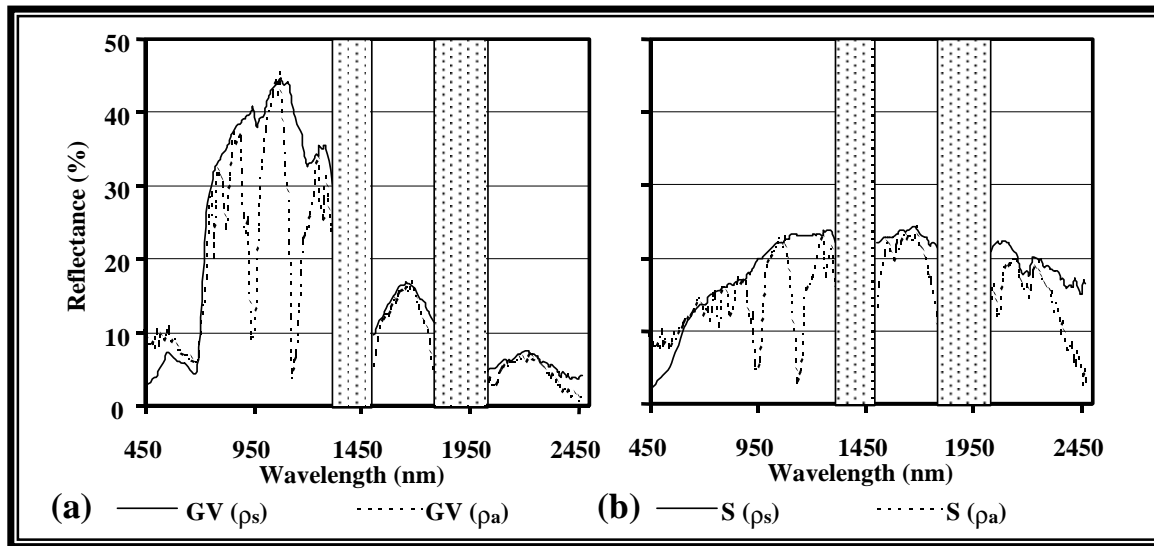


Figure 2 – AVIRIS-derived apparent (ρ_a) and surface (ρ_s) reflectance spectra of selected endmembers of green vegetation (GV) (a) and soil (S) (b). The vertical shaded columns around 1400 and 1900 nm indicate the two major intervals of atmospheric absorption.

To illustrate the impact of atmospheric scattering and absorption on the NDVI determinations from the use of narrow and broad R-NIR bands, Figure 3a shows the results obtained by using a fixed narrow NIR band at 923 nm and a variable placement for narrow and broad R bands. On the other hand, Figure 3b displays the NDVI variations for a fixed narrow R band at 677 nm and different positioning for narrow and broad NIR bands. In both figures, the results are shown only for calculations derived from the ρ_a and ρ_s spectra of GV. The results derived from ρ_a and ρ_s spectra of soil have been omitted in Figure 3 for a better graphic representation.

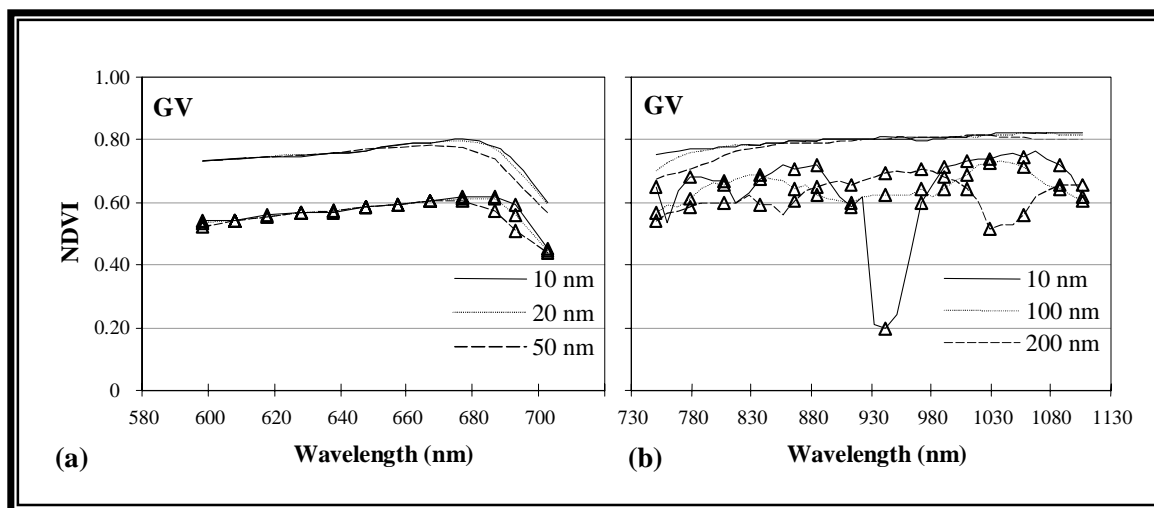


Figure 3 – NDVI variations, as a function of band positioning and bandwidth, derived from apparent (curves with triangles) and surface (curves without symbols) reflectance spectra of green vegetation (GV). In (a), the results were obtained with the NIR band fixed at 923 nm. In (b), the R band was fixed at 677 nm. The target is riparian forest.

As shown in Figure 3a, the NDVI values increase towards longer red wavelengths and reach a maximum around the center of the chlorophyll absorption band (677 nm) in both datasets (pa and ps). The effect of scattering, represented by the NDVI curve derived from the pa spectrum of GV, is to decrease the vegetation index values because of the additive contribution of the atmosphere in the red interval. The width of the R bands is not an important factor for NDVI determination from pa and ps spectra if the R bands are not inserted into the red edge domain (690-750 nm range), which causes a decrease in the NDVI values. The contrary occurs in the NIR interval. The presence of well-defined absorption bands due to oxygen and especially water vapor in the pa spectrum has a strong impact on the NDVI values derived from narrow NIR bands, especially those centered around the 940 nm water vapor absorption band.

Figure 4 shows the magnitude of the difference between the NDVI curves derived from the ps and pa spectra of GV, as a function of the positioning of R and NIR narrow AVIRIS bands. The results are also presented for the soil spectra. As illustrated in Figure 4a, the difference between the NDVI curves derived from corrected and non-corrected R bands for the atmospheric effects is almost constant and of the order of 0.2 for GV and slightly higher for S, considering a NIR band placement at 923 nm. The difference for the NIR bands increases substantially around the main intervals of atmospheric absorption and reaches values higher than 0.60 around the 940 nm water vapor absorption band for both targets. In Figure 4b, the main atmospheric windows, which comprises spectral intervals with small NDVI difference curves, are positioned in the 770-810 nm, 850-880 nm, and 1000-1070 nm ranges. The first two intervals are preferable to monitor vegetation from NDVI calculations because the shift of NIR bands towards shorter wavelengths tends to increase the NDVI contrast between GV and S and to produce also better fitted soil lines (Galvão and Vitorello, 1998; Galvão et al., 1999, 2000; Moreira, 2000).

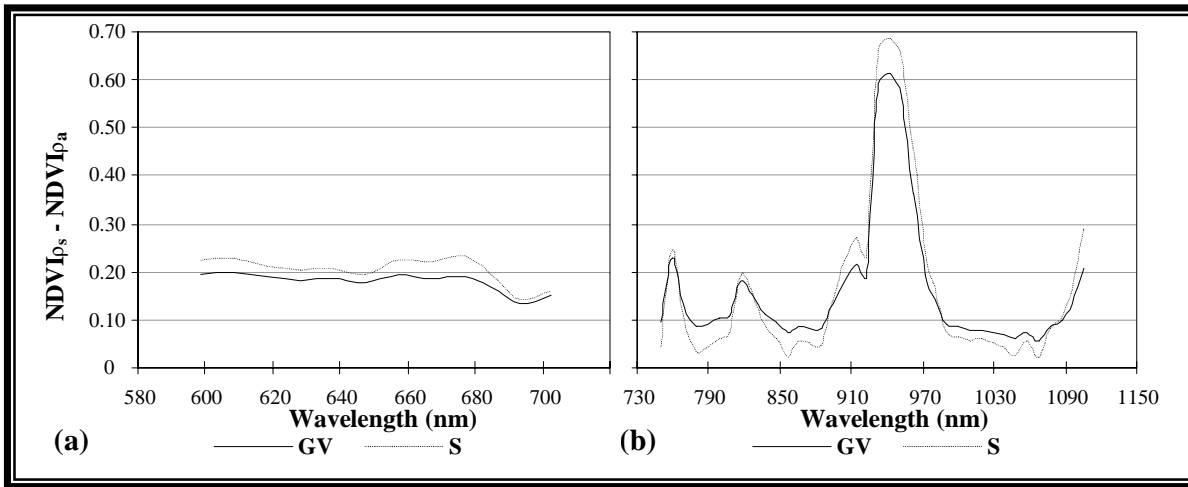


Figure 4 – NDVI difference curves derived from surface (ps) and apparent (pa) reflectance spectra of green vegetation (GV) and soil (S), as a function of the positioning of narrow R-NIR bands (10 nm of width). The results for GV are derived from Figure 3. In (a), the results were obtained with the NIR band fixed at 923 nm. In (b), the R band was fixed at 677 nm.

The sensors listed in Table 1 also produce NDVI differences introduced by atmospheric effects when compared to band positioning. As illustrated in Figure 5, the best results were obtained for MODIS with NDVI differences of 0.04 for S and of 0.07 for GV especially because of its NIR band placement in a very convenient atmospheric window. The worst results were obtained for AVHRR and MSS with NDVI differences higher than 0.10 for GV and S especially because their NIR bands encompass the strong 820 and 940 nm absorption bands due to water vapor.

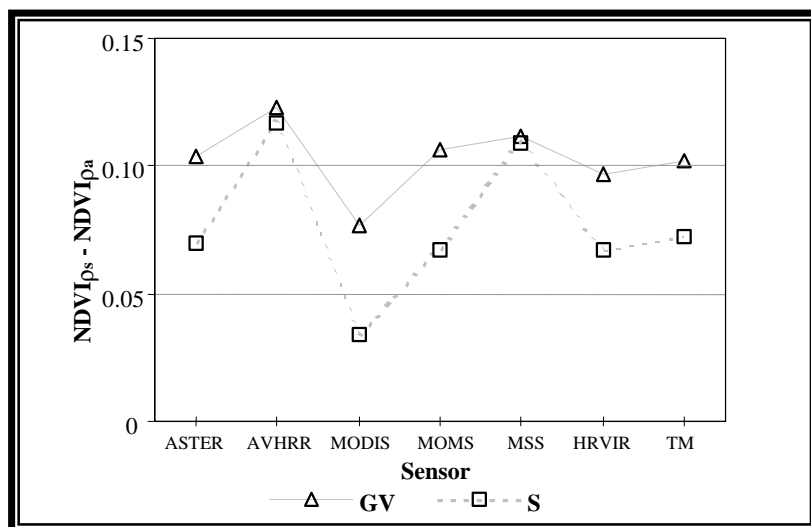


Figure 5 – NDVI difference curves derived from surface (ps) and apparent (pa) reflectance spectra of green vegetation (GV) and soil (S), as a function of the positioning of the R and NIR bands of the sensors listed in Table 1.

4. CONCLUSIONS

The results of this study indicate that the width of the R bands is not an important factor for NDVI determinations from pa and ps spectra if they are not inserted into the red edge domain (690-750 nm range). For the NIR interval, bandwidth is a very important factor because of the presence of well-defined absorption bands due to oxygen and especially water vapor in the pa spectrum that have a strong impact on the NDVI values derived from narrow NIR bands. When the nominal intervals of the R and NIR bands of some orbital multispectral sensors were simulated, the best results were obtained for MODIS, which presented smaller NDVI difference values, derived from atmospherically corrected and non-corrected data, of 0.07 (GV) and 0.04 (S). On the other hand, the worst results were obtained for MSS/Landsat 5 and AVHRR/NOAA 14, which showed NDVI differences higher than 0.10 because their NIR bands encompass absorption bands due to atmosphere constituents, especially the 940 nm water vapor absorption feature. The present results emphasize the fact that NDVI values derived from different sensors are not directly comparable, and the importance of carefully selecting spectral intervals for band placement if one considers to use narrow bands in the design of a sensor.

REFERENCES

- Asrar, G., Kanemasu, E.T. and M. Yoshida, 1985, Estimates of leaf area index from spectral reflectance of wheat under different cultural practices and solar angle. *Remote Sensing of Environment*, **17**, 1-11.
- Boardman, J. W. and F.A. Kruse, 1994, Automated spectral analysis: a geological example using AVIRIS data, north Grapevine Mountains, Nevada. In *Proceedings of the Tenth Thematic Conference on Geologic Remote Sensing*, ERIM, Environmental Research Institute of Michigan, Ann Arbor, MI, p. I-407 - I-418.
- Boardman, J. W.; Kruse, F.A. and R.O. Green, 1995, Mapping target signatures via partial unmixing of AVIRIS data. In *Summaries of the Fifth JPL Airborne Earth Science Workshop*, JPL Publication 95-1, v. 1, p. 23-26.
- Carlson, T.N. and D.A. Ripley, 1997, On the relation between NDVI, fractional vegetation cover, and leaf area index. *Remote Sensing of Environment*, **62**, 241-252.
- Elmore, A.J., Mustard, J.F., Manning, S.J. and D.B. Lobell, 2000, Quantifying vegetation change in semiarid environments: precision and accuracy of spectral mixture analysis and normalized difference vegetation index. *Remote Sensing of Environment*, **73**, 87-102.

- Epiphanio, J.C.N and A.R. Huete, 1994, Influence of sun-view geometries on the relationships among vegetation indices, LAI, and absorbed PAR. In *Proceedings of International Geoscience and Remote Sensing Symposium '94* (IGARSS'94), Pasadena, California. Piscataway: IEEE, Vol. 3, pp.1455-1457.
- Epiphanio, J.C.N. and A.R. Huete, 1995, Dependence of NDVI and SAVI on Sun/sensor geometry and its effect on fAPAR relationships in alfalfa. *Remote Sensing of Environment*, **51**, 351-360.
- Galvão, L.S. and I. Vitorello, 1998, Variability of laboratory measured soil lines of soils from southeastern Brazil. *Remote Sensing of Environment*, **63**, 166-181.
- Galvão, L.S., Vitorello, I. and R.A. Filho, 1999, Effects of band positioning and bandwidth on NDVI measurements of tropical savannas. *Remote Sensing of Environment*, **67**, 181-193.
- Galvão, L.S., Vitorello, I., and M.A. Pizarro, 2000, An adequate band positioning to enhance NDVI contrasts among green vegetation, senescent biomass, and tropical soils. *International Journal of Remote Sensing*, **21**, 1953-1960.
- Green, A. A., Berman, M., Switzer, P, and Craig, M. D., 1988, A transformation for ordering multispectral data in terms of image quality with implications for noise removal. *IEEE Transactions on Geoscience and Remote Sensing*, **26**, 65-74.
- Green, R.O., 1991, Retrieval of reflectance from AVIRIS measured radiance using a radiative transfer code. In *Proceedings of the Third Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) Workshop*, Pasadena, California (Pasadena: JPL publication 91-28), pp. 200-210.
- Holben, B.N.; Tucker, C.J. and C.J. Fan, 1980, Spectral assessment of soybean leaf area and leaf biomass. *Photogrammetric Engineering and Remote Sensing*, **46**, 651-656.
- Huete, A.R., 1989, Soil influences in remotely sensed vegetation-canopy spectra. In *Theory and applications of optical remote sensing* edited by G. Asrar (New York: J. Wiley & Sons), pp. 107-141.
- Latorre, M.L., Shimabukuro, Y.E., and L.A. Vieira Dias, 1998, Methods of atmospheric correction applied to AVIRIS data collected in tropical regions. In *Proceedings of the Ninth Brazilian Remote Sensing Symposium*, Santos - SP, September 11-18, CD-ROM, 10 pp. (in Portuguese).
- Moreira, R. C., 2000, Influence of band positioning and bandwidth of remote sensors and of atmospheric effects on the vegetation index determination. Master thesis in Remote Sensing. Instituto Nacional de Pesquisas Espaciais (INPE) (INPE-7528-TDI/735) (in Portuguese).
- Rouse, J.W., Haas, R.H., Schell, J.A. and D.W. Deering, 1973, Monitoring vegetation systems in the Great Plains with ERTS. In *Proceedings of Third Earth Resources Technology Satellite Symposium*, Washington, D. C.: NASA. Goddard Space Flight Center, Vol. 1, pp. 309-317. (NASA SP-351).
- Slater, P.N., 1980, *Remote sensing: optics and optical systems*. Reading: Addison Wesley,. 575 pp.
- Teillet, P.M., Staenz, K. and D.J. Williams, 1997, Effects of spectral, spatial, and radiometric characteristics on sensing vegetation indices of forested regions. *Remote Sensing of Environment*, **61**, 139-149.